ASSESSMENT OF THE EFFECTS OF GREYWATER DISCHARGED BY USING STREETER-PHELPS MODEL

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ABSTRACT

Greywater is generated from household activities in bathroom, kitchen and laundry. Pollution of wastewater occurs when the greywater is discharged directly into the stream from the houses and accumulates in the drain. The organic pollutants and suspended particulate matter from greywater may cause depletion of oxygen content in the water which lead to unpleasant odours and increased organic matter degradation time. The aim of this study is to assess the effect of greywater discharged using the Streeter-Phelps model. The first objective of this study to determine the raw greywater characteristics and variations of greywater pollutants loading rate (BOD_5). Secondly, the assessment of greywater pollution modelling was measured by using Streeter-Phelps model. The questionnaire were conducted to obtain the household demographic profiles and household activities practice data from respondents. Five sampling points which involve $Drain_1$ to $Drain_5$ for greywater study came from 48 households before mixing with stream. After greywater sampling, hydraulic and physicochemical parameters were measured at intervals from $Station_0$ to $Station_7$ along the stream after mixing with greywater discharge. The results of greywater quality were 172 mg/L for BOD_5, 400 mg/L for COD, and 4.5 for pH. The results showed that the highest BOD_5 loading rate for daily flow rate was observed at $Drain_3$ with the values of 63 kg/day and 369 m^3/day. These drains have a high frequency of household activities and number of occupants leads to high amount of pollutant loading rate produced from greywater drainage. The validity of the simulated DO from Streeter-Phelps model proved that the regression of Thomas slope method indicated a good fitting with laboratory analysis. Furthermore, the curve of the measured and simulated DO showed a gradual increase in the DO movement, indicating a rapid self-purification of the stream. The DO deficit (D_t) and time critical (t_c) were 3.54 and 3.80 mg/L and 0.007 per day, respectively, as recorded at the distance of 10 m upstream ($Station_1$) of the discharge point. Findings

show that the degradable organic matter and travel time as a critical oxygen deficit point occurred at 10 m upstream as the kinetics of BOD reaction. Hence, the greywater discharge with mixing stream showed no risk of pollution occurrence near the river flow in this study.

ABSTRAK

Air sisa rumah dihasilkan dari bilik mandi, dapur masak dan mencuci pakaian. Pencemaran air sisa berlaku apabila air kelabu dilepaskan secara langsung ke dalam anak sungai dari rumah dan berkumpul dalam longkang. Bahan pencemar organik dan bahan terampai dari air kelabu menurunkan kandungan oksigen dalam air yang mengakibatkan bau busuk dan meningkatkan masa penguraian bahan organik. Tujuan kajian ini adalah untuk menilai kesan air sisa rumah yang dilepaskan menggunakan model Streeter-Phelps. Objektif pertama kajian ini adalah untuk menentukan ciri-ciri air sisa rumah dan variasi kadar beban pencemar BOD5 bagi air sisa rumah. Objektif kedua, menilai pemodelan pencemaran air sisa rumah dengan menggunakan model Streete-Phelps. Temubual dan soal selidik telah dibuat untuk mendapatkan profile demografik isi rumah dan amalan aktiviti harian dari responden. Lima point pensampelan melibatkan longkang pertama sehingga longkang kelima terdiri daripada 48 buah rumah sebelum bercampur dengan anak sungai. Selepas pensampelan air sisa rumah, parameter hidraulik dan fizikokimia telah diukur pada selang dari Stesen1 hingga Stesen7 selepas anak sungai bercampur dengan air sisa rumah. Keputusan kualiti air sisa rumah adalah; 172 mg/L untuk BOD5, 400 mg/L untuk COD, dan 4.5 untuk pH. Keputusan ini menunjukkan kadar tinggi beban BOD5 untuk kadar alir harian didapati pada longkang ketiga dengan nilai 63 kg/hari dan 369 m3/hari. Saliran longkang ini mempunyai kadar tinggi kekerapan aktiviti isi rumah dan bilangan penghuni membawa kepada jumlah tinggi bagi kadar beban pencemar dihasilkan dari air sisa rumah tersebut. Pengesahan simulasi DO dari model Streeter-Phelps membuktikan dalam regresi kaedah cerun Thomas, menunjukkan pemasangan yang baik dengan analisis makmal. Selain itu, lengkung diukur dan simulasi DO menunjukkan peningkatan secara beransur-ansur dalam pergerakan DO, menunjukkan pembersihan laju dalam anak sungai. Defisit DO (Dt) dan masa kritikal (tc) adalah 3.54 dan 3.80 mg / L dan 0.007 sehari, telah direkodkan pada jarak 10 m hulu (Stesen1) pada titik pelepasan. Menunjukkan bahawa degradasi

bahan organik dan masa perjalanan sebagai point defisit oksigen kritikal pada hulu 10 m sebagai kinetik reaksi BOD. Oleh itu, pelepasan air sisa rumah dengan campuran anak sungai tidak menunjukkan risiko pencemaran yang berlaku berdekatan dengan aliran sungai dalam kajian ini.

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LIST OF SYMBOLS AND ABBREVIATIONS

BOD	-	Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand DO
	-	Dissolved oxygen
D_t	-	Dissolve oxygen deficit
D_o	-	Initial deficit after stream and greywater have mixed
e	-	Exponential
k_d	-	Deoxygenation rate
k_r	-	Reaeration rate
L_o	-	Initial ultimate BOD after stream and greywater have mixed
OL	-	Organic loading
pH	-	Potential of hydrogen
t_c	-	Critical time
TSS	-	Total Suspended Solids
TN	-	Total Nitrogen
TP	-	Total Phosphorus
Q	-	Discharge
V	-	Velocity
APHA	-	American public health association

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Greywater sources play a critical role in the variation of pollutant concentration levels compared to blackwater. Boyjoo, Pareek & Ang (2013) claimed that the pollutant concentration levels of household greywater from kitchen, dishwashers, and laundry machines are equal to or greater than that available in blackwater. Major contaminants reported within the effluents of these domestic residential include a very high loading of organic pollutants from household activities (Singh and Sharma 2015). Mohamed *et al*. (2017) claimed that the biochemical oxygen demand (BOD5) in greywater may reach up to 117 to 178 mg/L in combined discharges of kitchen, bathroom, and laundry greywater in Malaysia. This is considerably higher than the safe level of water quality stipulated in the Environment Quality Regulations 2009 and the BOD5 (50 mg/L) for standard effluent discharge.

Moreover, greywater from kitchen had acidic pH (Bakare, Mtsweni & Rathilal, 2017) due to the presence of many organic materials from food, dishes, oil and grease as reported by Mohamed *et al.* (2013); Wurochekke *et al.* (2014); Sultana and Alamgir (2016). Highest COD concentration has the most polluting strength in raw greywater discharged from kitchen activities (Sultana and Alamgir, 2016; Bakare *et al.,* 2017). In addition, the value of COD at 2046 mg/L indicated a high level of organic compounds in greywater flow (Sultana and Alamgir, 2016). These findings were similar to those obtained in a study by Dwumfour *et al*. (2017), who found that kitchen activities have the highest value of BOD5 due to high organic matter from food with an average value of 370 mg/L. The BOD5 concentration for laundry was lower with an average value of 269 mg/L and that from bathing was the lowest with an average value of 139 mg/L.

In villages, greywater and blackwater are separated from the sewerage network, in which the sewage goes to the septic tank whilst the greywater is disposed into the nearest drainage. This is a common practice in many of the village houses in Malaysia (Wurochekke et al., 2014). Mohamed et al. (2014) reported that commonly, the raw greywater from household activities (kitchen, laundry and bathroom) in village house is discharged directly into streams or rivers. The direct discharge of greywater into drainages has potential negative effect on the environment and human health (Ajlouni and Al-ajlouni 2015). The process of dissolved oxygen reduction is due to the decomposition of organic waste and lack of oxygen supply for the aquatic organism in the water (Couto et al. 2013). The excess nutrients could lead to the growth of large algae populations known as an algal bloom (Olanrewaju and Llemobade 2015).

Therefore, the direct discharge of greywater to the natural water system could potentially contribute to the eutrophication phenomenon due to excess nutrients in the greywater (Mohamed et al. 2014). Stagnant drainage water which contains greywater could lead to unpleasant odours from the release of nutrients and provide a breeding environment for insect pests (Mohamed et al. 2013). Furthermore, low water flow and stagnant water contribute to the presence of Anopheles larvae in drains (Castro et al., 2010). Some of the wastes, especially greywater discharge, whichis non-biodegradable and acidic were also found to interrupt the auto-purification processes of streams and rivers (Maamar, Djillali & Amine, 2014).

The high contents of organics in the greywater could also reduce the water quality. Al-Badaii, Shuhaimi-Othman & Gasim (2013) revealed that the water quality assessment of the Semenyih River, Selangor, Malaysia had a low BOD5 of 2.4 ± 9.8 mg/L, while raw greywater was 108.07 ± 8.69 mg/L. However, the value rate of river quality depends on the purification process in water bodies due to the greywater discharge. Hence, several factors of self-purification capacity include the water body velocity, depth, discharge and temperature (Omole et al., 2012). Maamar et al., (2014) stated that the self-purification capacity of the river, which is limited by relatively low DO saturation levels, is threatened by the wastes being discharged into it at varying intervals.

The Streeter-Phelps model (oxygen sag curve model) is a water quality modelling tool used to evaluate water pollution. Nas and Evin (2009) used this model at the Harsit Stream flowing into the Black Sea. The stream isa major catchment area in the north-eastern part of Turkey, which had the problem of municipal and industrial wastewaters discharge into the streams. The model was suitable for predicting the decrease in DO in the Harsit Stream along a certain distance due to the degradation of BOD. Model transport simulation using the Streeter-Phelps model was selected because the model can predict the changes in surface water quality at a certain distance after mixing of the effluent discharged in the stream (Nas and Evin 2009). It is considered as an effective tool and treatment innovation for future management of water streams (Haris *et al*., 2016).

Furthermore, the Streeter-Phelps model is typically used by engineers to simulate the hydrological processes of streams or rivers. The model can measure the water quality changes, which can be used to improve water resource management system. Maamar *et al.*, (2014) stated that the Streeter-Phelps model was used to study the river quality of the Wadi Cheliff River focusing on the need for self- purification, hydraulic properties, and physicochemical characteristics. It was found that the Wadi Cheliff River has a normal capacity but limited ability to purify itself from the many pollutants due to domestic or industrial wastewater discharge (Maamar *et al.*, 2014). These could happen due to the presence of wastes (non- biodegradable), which slows down the self-purification processes in the river. The dry season indicates that the flow is low, thereby generating low flow velocity and temperatures higher than 29 °C decreases the solubility of the DO (Maamar *et al.*, 2014).

The prediction of DO movement levels in a water body after the discharge of organic waste showed that the mathematical equation in the Streeter-Phelps model was accepted as an efficient tool to the analysis of pollution status in streams or rivers (Sinha, Aggarwal & Tyagi 2014). Maroneze *et al.* (2014) explained that the total change in oxygen shortage was equal to the difference between the two rates of deoxygenation (Kd) and reaeration (Kr) at any time. The changes in the oxygen content of polluted stream or rivers were studied through the Streeter-Phelps model. The model used the DO sag curve profile to predict the DO movement with reasonable accuracy in the contaminated water bodies (Singh and Sharma 2015).

Therefore, measurement of the DO in the stream from the greywater discharge of the household activities was studied. The Streeter-Phelps model was used in describing the DO decreases in a stream. A certain distance by BOD depletion identified the critical DO level at certain distance of drainage as affected by the greywater discharge.

1.2 Problem Statement

Nowadays, the increasing in disposal of domestic greywater through human activities is neglected along with rapid growing of human populations. Typically, village areas are disconnected from the sewerage network, thus the direct discharge of greywater is a common practice. For instance, a village in Parit Raja Darat, Parit Raja, Batu Pahat has a conventional practice whereby the greywater is discharged into the stream or river nearby without treatment. The direct discharge of greywater into the stream without treatment affects plants and organisms living in these water bodies (Noman et al., 2018). At the same time, greywater may contain excess nutrients (nitrogen and phosphorus), which also negatively impact on aquatic life and surface water quality through eutrophication (Klammer 2013; Fowdar 2018). Maamar et al. (2014) stated that low flow of stream gives rise to possibilities in contributing to water stagnant can cause unpleasant odours from the production of bacteria. The process of eutrophication influences the growth of large masses of algae known as algal blooms (Oteng-Peprah, Vries & Acheampong, 2018).

The main focus of previous studies has been mainly on stream or river water quality, which consists of domestic or industrial effluents (Singh and Sharma 2015; Uzoigwe, Maduakolam & Samuel et al., 2015; Deborah et al., 2017). Singh and Sharma (2015) observed that heavy loading from organic pollutants and suspended particulate matter caused depletion of oxygen content in water bodies. This problem aggravates the purifying capacity of the river flow due tothe presence of various contaminants from wastewater effluents discharged into the river (Maroneze et al., 2014). In addition, there are still lacking review in Malaysia on greywater discharge in the stream or river by using Streeter-Phelps model. Only few studies were conducted on water quality modelling by using Streeter-Phelps which focus on greywater pollution as reported by Zainudin et al. (2015); Nuruzzaman, Al-mamun & Salleh, (2017). In their studies, they use the Streeter-Phelps model to evaluate the degree of water contamination at the river areas, which contributes the problem of domestic sewage discharged directly into the water bodies or river without any treatment in Malaysia.

However, there is lack of data on the determination of BOD decomposition and kinetics rates due to deoxygenation (Kd) and reaeration (Kr) of stream or river areasin Malaysia. The direct discharge of the greywater can increase the level of contaminants resulting in low DO concentrations in streams which could also affect nearby rivers (Deborah et al. 2017). Low DO also causes microorganisms that require oxygen supply to oxidize the organic wastes (Singh and Sharma 2015).

Therefore, the Streeter-Phelps model was selected in the present work to determine the DO deficit (Dt) and time critical (tc), based on the measured and simulated DO. Consequently, the input values for the model will provide accurate information required to estimate deoxygenation (Kd) and reaeration (Kr) based on the mathematical equations of the Streeter-Phelps model (Maroneze et al., (2014). Lastly, the model will provide reasonable approximations within the predefined limits, which is the novelty of the current work.

1.3 Objectives of the Study

The specific objectives of the study are:

I. To determine the raw greywater characteristics and variation of greywater pollutants loading rate (BOD5).

II. To assess the greywater pollution modelling by using the Streeter-Phelps model.

1.4 Research Hypotheses

i. Greywater characteristics used for determining quality parameters may have a higher concentration based on observations of the significant pollution of greywater discharged into a drain.

ii. Variation of greywater pollutant loading rate can represent the total pollutant load which shows a high BOD5 in greywater discharge.

iii. Streeter-Phelps model can be used for determining DO deficit (Dt) andtime critical (tc). The most critical DO and time in a stream, along with a certain distance, is expected at the initial point of household greywater discharge.

iv. The combination between measured and simulated DO is expected to rise in the DO level following a slow self-purification of the stream.

v. The measurement of DO movement in the stream from greywater discharge is expected, as the quality of the river deteriorates when household greywater is disposed of directly into a stream near the river.

1.5 The Scopes of the Study

The present study is focused on investigating the rates of DO reduction in a stream along a certain distance through the degradation of BOD using the Streeter-Phelps model. The model analysed the water quality in the stream, due to greywater (bathroom, laundry and kitchen) directly discharged into the stream. This study was conducted at Parit Raja Darat village, Parit Raja, Batu Pahat, Johor, Malaysia with the location coordinates (2.024 N and 102.618 E).

The information in the case study was acquired using questionnaire to obtain household demographic profiles and household activity practices data from respondents. The form was distributed to the villagers, as much as 48 houses, representing five drains for greywater sampling. The 48 houses were chosen from site investigation which showed that the pollution of wastewater came from the greywater discharge from five drains based on drainage lines and number of houses. Grab samples and measurement of fieldwork were used to determine the variation of greywater pollutants loading rate (BOD5) in the morning (8.00 a.m. to 12.00 p.m.). Samples were collected once every weekend during peak household activities period. The flow rate Q (m^3/s) was measured and all samples were collected in polyethylene containers before analysis for pH, BOD5, and COD.

After greywater sampling, stream sampling was done by grab method in the evening (5.00 p.m to 7.00 p.m) on the same day. Samples were measured at intervals from Station0 to Station7 along the stream after mixing with greywater discharge. Stream sampling (BOD5, DO, pH and temperature) and fieldwork measurements (distance, depth, width and velocity) were performed to determine the DO deficit (Dt) and time critical (tc). All parameters were tested at the Environmental Engineering laboratory of the Micro-Pollutant Research Centre (MPRC) at Universiti

Tun Hussien Onn Malaysia (UTHM). All data were calculated using the mathematical equations of the Streeter-Phelps model. Finally, the greywater pollution modelling was established using the Streeter-Phelps model and the DO sag curve profile as a guide. The DO sag curve profile was used for combined measurement and simulation of DO in the stream. The DO value was also measured to predict the movement condition of DO for the self-purification process in the stream.

1.6 Significance of Research

The aim of this study was to evaluate the effects of the drainage pollution due to greywater discharged from household activities based on the Streeter-Phelps model. This model is used as a water quality modelling tool in water pollution to measure the movement condition of DO when greywater is discharged into streams. Afterwards, the assessment process of the Streeter-Phelps model can show whether or not pollution occurs when the household greywater is discharged directly into stream near the river. The findings could be useful to improve the execution of more effective greywater management systems for sustainable future drainage. This model also helps to estimate and identify the DO critical level in pollution streams through the mixing of raw greywater.

1.7 Thesis Outlines

This thesis consists of five chapters. Chapter 1 presents a brief introduction on household greywater, its characteristics and problem statement regarding the significant portions directly discharged from drains into the streams. A brief introduction on the variation of greywater pollutants, predicted movement DO conditions and the process of self-purification in the stream were presented. In this study, the Streeter-Phelps model was used for pollution modelling of greywater. Furthermore, the objectives, hypothesis and scope of study have been highlighted.

Chapter 2 contains the background of the study on different topics related to this research. This chapter presents information on the general characteristics of household greywater, consequences of improper disposal of greywater into the environment, pollutions loading rate of greywater and experimental assessment of pollutants and impacts on water quality from hydrological transport model.

Chapters 3 describes the procedure of the test methods for overall research in this study including the testing standards, materials characterization, sampling methods, experimental instruments, and formulation of mathematical modelling studies.

Chapter 4 presents and discusses the findings of this study. These include the analysis results for greywater characteristics for the three parameters: BOD5 (mg/L), COD (mg/L), pH and the variation of greywater pollutant loading rate (BOD5). In addition, the DO deficit (Dt) and time critical (tc) after mixing with greywater and the stream was also evaluated using the Streeter-Phelps model by comparing the measured and simulated (DO).

Chapter 5 presents the main conclusion of the overall research findings based on experimental and analytical analyses along with a possible recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses all related previous studies to provide the gaps of knowledge. The first approach of this chapter is the discussion on the characteristics of the raw greywater and variation of greywater pollutants loading rate (BOD5) and their effect from the direct discharge. Next, the topic was explained on the dissolve oxygen deficit (Dt) and time critical (tc) after mixing of the greywater discharge in the stream by using Streeter-Phelps model. Finally, the view on the comparison between measured (testing laboratory) and simulated DO (mathematical equation) to establish the greywater pollution modelling is discussed.

2.2 The Nature of Greywater

Greywater is a general term for wastewater generated from households activities except for the sewage. The sewage is known as blackwater. Greywater was generated from baths, showers, hand basins, washing machines, dishwasher and kitchen sinks (Antonopoulou, Kirkou & Stasinakis, 2013). Albalawneh and Chang (2015) stated that light greywater (low strength greywater) was originated from bathroom and washbasin. While greywater sources from laundry and kitchen were usually categorised as dark greywater, which categorised as high strength greywater. The level of organic contaminants was less in this type of greywater production from household activities. Usually, kitchen and dishwasher wastewater are excluded from

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